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PREDICTION OF MAN'S VISION IN AND FROM THE MERCURY CAPSULE

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The prospect of manned orbital flight has created considerable interest concerning what the astronaut might see in and from the capsule. Little information exists in an integrated form about man's visual capability in space, particularly in relation to a specific vehicle and its mission. Much discussion in the past seems to have been devoted to protecting him from extreme effects, rather than enhancing his sight. Vision serves as man's primary source of complex information, and in the space environment it may have even greater value, since it can substitute for bodily orientation inputs from sense modalities that lose their effectiveness because of weightlessness. The importance of adequate vision becomes greater as the "wooden man" concept of space flight is abandoned and increasing emphasis is placed upon the versatility afforded by the integration of the man and machine. Military space vehicles may require man to function even more actively.

This paper describes some of the visual factors examined during the design of the NASA Mercury capsule, and then predicts what the occupant might see during a mission. The predictions are based on capsule operation and design, the space environment, and man's visual characteristics. Obviously, design limitations existed which dictate compromise to maximize over-all system effectiveness. The primary one in the visual area was the limited electrical power available. Secondary ones were the requirements for heat dissipation and sufficient light for interior cabin photographs.

VISUAL CHARACTERISTICS OF CAPSULE OPERATION AND DESIGN

The orbital altitude will be approximately 120 miles, at a speed of 17500 mph. The capsule will be launched from Cape Canaveral in an easterly direction, and for the basic mission there will be three orbits of approximately ninety minutes each for a total of four and one-half hours, with re-entry initiated west of the California coast, for recovery east of Florida. Present plans call for an early morning launch. The astronaut faces rearward during orbit and retrograde.

Primary control of the Mercury vehicle is automatic and it can proceed from launch through landing without the operator turning a hand. However, a trained man is important and can function: (1) as a scientific observer of astrophysical, biological, and psychological phenomena; and (2) as an integral part of the machine to increase mission success beyond that for the automatic mode by initiating corrective actions for malfunctioning components, and by adding flexibility to the system.

There are certain design characteristics of the capsule which have significance in defining the astronaut's visual capabilities.

INSTRUMENT PANEL – The instrument panel is a major source of information on capsule system functioning through its displays, and caution and warning lights (Figure 1).

Colors were used at the suggestion of the astronauts to define functional groupings. The sequence lights on the left side of the panel use red and green lamps to indicate the status of the system. The amber caution lights on the right side of the panel are augmented by auditory signals. The panel groupings and instrument markings hold up well under both red and white lighting. The reflectivity of the panel and cockpit structure represents a compromise between the need for glare reduction and adequate diffusion of inside and outside light.

PERISCOPE – The periscope can be used as a backup display for manual attitude control, and also to determine the capsule's position and course (Figure 2). The field of view is 180° the earth's horizon is at 150° for a 120-mile altitude, and the circular area covered is approximately 1800 miles in diameter. The center of the 360° horizon circle at normal vehicle attitude represents the end of a vertical line to the core of the earth. Low (1/10) and high (5/8) magnifications can be selected. In the high power option, the center view field is 19°. Indices are available both on the periscope face and on a sun-moon scale around it. The viewing distance is 24 inches with the monocular eye freedom about one inch in diameter. Objects are extremely clear in the central area of the scope, but become distorted near the edge because of the extreme wide angle of view, curvature of the earth, and increased atmospheric penetration. Red, yellow, high density neutral, and opaque filters can be selected. Light transmission is about 20 to 25 per cent without a filter, and sufficient glass is present to absorb harmful ultraviolet light. Attitude control is accomplished by centering the horizon circle to appropriate markings on the scope face. Navigation features allow determination of vehicle altitude using adjustable indices, track using drift lines, and position by identification of gross landmarks. Special maps, timers, and an earth-path indicator are available as navigational aids. The field of view, time to view, and object size appear to be important variables in defining what ground features might be observed (Reference 11).

Studies have been accomplished using a simulation of the Mercury periscope and earth to determine the feasibility of navigation. An earth path can be predicted successfully without excessive demands on the operator's time.

CENTERLINE WINDOW – A centerline window is located above and forward of the astronaut's head. It can be used for attitude control under certain circumstances, and to observe the earth and sky. It consists of four layers of glass coated with an anti-reflectant. A red filter and a solid shield are provided (Figure 3). The transmission index at optimal viewing angles ranges around 50 per cent because of the thickness of the glass layers.

CABIN LIGHTS – Two four-watt warm white fluorescent lights are used to illuminate the instrument panel and capsule interior. These have two sliding shields, one opaque and the other red (620 mμ), which allow a continuous variation of intensity in either the white or red range. A mounted flashlight is provided to permit emergency illumination if required.

VISUAL CHARACTERISTICS OF THE PHYSICAL ENVIRONMENT

Predictions about man's visual capability in the Mercury capsule require information on relevant characteristics of the earth, sky, and horizon at orbital altitude for the light and dark side of the earth. Information regarding the probable appearance of this environment to the human eye is particularly scarce for the dark side of the earth. Photographs using infrared or film balanced for light on earth, although valuable, are not necessarily a faithful reproduction of the visual environment. Several characteristics of the space environment were examined.

SPECTRAL COMPOSITION – Ultraviolet light (313 $m\mu$ or less) increases in intensity by a factor of four or five outside the earth's atmosphere (Reference 16).

INTENSITY (Reference 5) – Illuminance (E) in the visual spectrum increases by about 30 per cent at orbital altitudes over the value on earth. At 100,000 feet and 30° solar elevation, the intensity is about 13,500 foot-candles, which is comparable to that expected at orbital altitudes. In contrast to illuminance, zenith brightness (B) of the daylight sky at 85 to 100 miles approximates a moonlight night and at orbital altitudes approaches total darkness, thus stars become visible. This brightness-illuminance difference means that there will be strong contrast effects; since the sky becomes dark and the light sources more intense. The sun will appear as a bright disc without its aureole and the moon will appear somewhat brighter. The increased contrast has interesting implications for visual adaptation.

SCATTER (References 5 and 8) – Light scatter resulting from water vapor, smoke, dust, organic matter, and sea-salt nuclei is not significant at altitudes above 100,000 feet. This means that the sun's light in particular will have a "searchlight" effect where there will be dark shadows and brightly lighted areas (Reference 16). However, shadows within the interior of the capsule might be lightened somewhat by the diffusion of light from weightless particles and moisture activated by fans, and light reflected from the interior surfaces.

CLOUD COVER – The most conspicuous visual effect at orbital altitude, other than day-night cycle, is the wide variation in cloud cover (References 3 and 12). Clouds have two significant visual effects: they block the view of the earth and create shadows, and they reflect sunlight to increase illuminance. These have implications for both navigation and protection of the astronaut from high intensity light. The mean cloudiness over the earth has been estimated as 54 per cent for land and 58 per cent for water (Reference 5). However, in the latitudes for the Mercury mission, a 6/10 or more cloud cover is estimated to occur only about 30 per cent of the time. This value will be lower in summer and somewhat higher in winter. Some water or land should be visible almost all the time through the periscope because of its wide field of coverage. However, a NASA Tiros I picture shows a cyclonic cloud 2000 miles in diameter in the central Pacific. The albedo, or proportion of sunlight reflected back in space, has a mean of around 0.35 for the earth, and about 0.50 for clouds (Reference 5). By comparison, the moon's albedo is 0.07. This has significance for the occupant of the vehicle in terms of comfort and adaptation. At night translucent clouds may serve as a diffusing medium for the light from major population centers, possibly producing a distinguishable landmark.

HORIZON (Reference 7) – The earth-sky discontinuity is an important exterior visual reference for backup control of the capsule's attitude in pitch and roll. During daylight, the ground horizon is often obscured by haze and is not sharp. The upper boundary of the haze or "photometric horizon" is presumed to correspond to the height of the troposphere and usually appears sharp. However, the sharpness will vary with the haze bands that cause multiple horizons or stratums, and in about two out of eight cases there will be a diffuse boundary. A different situation exists on the dark side of the earth, since the discontinuity results from the earth masking the heavens and will appear as a black hole against a star background. The stars will no longer scintillate, they should be brighter by about 30 per cent, and some differences in color might be apparent (Reference 8). Stars will be visible and constellation patterning recognizable at night when the observer is dark-adapted and capsule lighting conditions are appropriate. The moon, airglow, starlight, galactic light, and zodiacal light in decreasing order of intensity, will furnish a very faint light when the vehicle is on the dark side of the earth (Reference 2). Air glow will be below the vehicle.

DURATION OF LIGHT – Light will change from dark to light and back to dark every 90 minutes during each orbit. Equal amounts of darkness and light will be encountered because of the orbital path. The increase in daylight because of orbital altitude will be negligible.

APPEARANCE OF THE EARTH – Simulation studies using Mercury parameters, and examination of orbital altitude photographs suggest some of the gross topography that may be distinguishable during daylight (Reference 3). Vision at orbital altitudes is characterized by the perception of shape and pattern rather than the resolution of small objects.

1. Coast lines such as the west and east coasts of Florida differentiated by their contour and location with respect to the water boundary.

2. Large lakes as Victoria, bays as San Francisco, and gulfs as California which have clearly defined shapes and positions in relation to land masses.

3. Moderate sized islands with distinctive shapes, as Madagascar.

4. Mountain ranges with characteristic ridges as the Rockies, especially when shadows increase their contrast.

5. Patterning of groups of small islands, especially in the South Pacific.

6. Major river systems, as the Rio Grande, bordered by vegatation that contrasts with the area and accentuates their width.

The area from Australia and the East Indies to the west coast of the United States contains few perceptually distinguishable features except for some islands of moderate size, and the patterning of smaller islands.

The extent to which various types of earth's surface reflect sunlight has significance since this may differentiate areas visually, especially if sharp boundaries occur as where the dark sea contrasts a light snow-covered shore. Some representative values (Reference 6) are:

Surface	Sunlight Reflected (%)
Ocean	3 to 5
Dry grass	3 to 6
Deciduous forest	3 to 10
Ground	10 to 20
Rocks	30
Lush grass	15 to 25
New snow	70 to 86

The color of the earth viewed from orbital altitudes will be cold and probably not distinct. It will tend towards blue-green for the water and vegetated regions and reddish brown over desert areas (References 4 and 16).

The texture of the earth and water, which might serve as an exterior visual reference for yaw control, usually will be homogeneous and of marginal value.

Topographical features will be visible rarely on the dark side of the earth. Artificial light from major population centers such as New Orleans might be seen and occasionally have a distinctive outline caused by a lake or coastline.

VISUAL CHARACTERISTICS OF MAN

The general characteristics of man's visual processes are well known (References 9 and 13). Therefore, only those few aspects of vision and perception that have particular importance for the orbital mission will be reviewed here.

LIGHT SENSITIVITY – The great range of sensitivity of the eye can be illustrated by its threshold for an achromatic point light source where the background luminance (B) can vary from 100 million to one. However, at lower light levels, vision is achromatic, has reduced acuity, and is parafoveal. The "practical" threshold illuminance (E) value for an aviator has been estimated by several authors as about 0.15 lumens/km^2, which is equivalent to perceiving a star of the third magnitude (Reference 8). There are about 530 stars brighter than the fourth magnitude, half of which are below the horizon (Reference 10). Although theoretically possible, an aviator cannot see stars of a greater magnitude because parafoveal vision is not ordinarily used, and the light necessary to read instruments raises the threshold. Atmospheric attenuation is reduced somewhat at orbital altitude, but this gain in illuminance is more than forfeited by the light transmission loss through the periscope and window.

It should be apparent now that the astronaut's scotopic vision must be enhanced as much as possible. Dark adaptation, oxygen level, acceleration, lighting contrast, and training are significant factors (Reference 13). Of most immediate concern is securing a dark adaptation level that allows both the capsule instruments and a significant number of stars to be observed together. Adaptation is a function of variables such as the intensity, duration, and wavelength of preadapting light. Its maintenance is complicated by the rapid "day-night" cycles and the intensity of light in orbit, particularly if the astronaut inadvertently looks at the deceptive sun through the window or highly reflective clouds through the periscope. Filters with appropriate characteristics should allow adequate dark adaptation when utilized properly.

ACCELERATION AND VIBRATION – Acceleration decreases the extent of the visual field. Within limits, increased light intensity can compensate for acceleration effects (References 14 and 15). Vibration, especially in the low frequency high amplitude range, can reduce acuity by influencing both the eye and object viewed (Reference 13).

GLARE – A relatively bright light source or its reflection produces glare which can reduce acuity and prove irritating. Multisurfaced reflectors, such as the window and periscope, may have some "ghosts" despite the anti-reflectants.

MASKING – Ambient illumination can have a masking effect that prevents a signal from being seen. When the window or periscope is used at night, high interior light levels will reduce acuity for higher magnitude stars (Reference 13).

CONTRAST – At night, object-background contrast will be reduced and visual acuity will be less. On the light side of the earth, the brightness contrast ratio will be high under many conditions and cause discomfort if exterior light sources are unfiltered.

PERCEPTION – The perceptual process where the brain ultimately interprets signals from the eyes might possibly modify the visual sensation in unpredictable directions because of the unique circumstances encountered in space and the interrelation of sensory inputs (Reference 1).

ESTIMATE OF THE ASTRONAUT'S VISUAL CAPABILITY

The significant factors influencing the astronaut's visual capability are:

1. Transmission indices of optical devices and their viewing angles.

2. Area coverage, magnification, and time-to-view for optical devices.

3. Interior/exterior ambient illumination ratio.

4. Object-background contrast.

5. Atmospheric attenuation and masking from clouds and other phenomena.

6. Topographical characteristics of the earth, and brightness and patterning of heavenly bodies.

7. Scotopic vision achieved by the astronaut.

8. Environmental effects on vision such as acceleration and vibration.

A summary of anticipated visual capabilities has been made by mission phase based on considerations described in preceding sections. Most estimates are based on a subjective integration of the variables because experimental or observational approaches are not feasible presently. It must be recognized that these estimates are somewhat speculative.

LAUNCH – High acceleration loads and vibration during launch restrict the astronaut's peripheral visual field and reduce acuity for small letters and instrument indications. However, the central portion of the panel and most warning lights will probably remain visible even during the initial period of acceleration. The red filters or shield will probably be in place on the window as a protection from booster flare. The horizon will be clearly visible during the day. At night, it might be seen through the window and periscope after booster separation has occurred and the red filters are removed if an adequate level of scotopic vision has been achieved.

ORBIT – On the light side of the earth and with the window protective devices removed, objects in the capsule and outside the direct rays of the sun will be difficult to see because of the "searchlight" effect. The light earth, dark sky, and horizon will be seen clearly. Gross topographical features on earth should be visible and navigation will be possible except when cloud coverage interferes and passage is over areas without distinct landmarks. Internal vision will be more effective with the shield closed and under artificial illumination. Attitude control using the horizon will be possible in pitch and roll, but marginal in yaw unless a distinct pattern is available on the earth's surface.

On the dark side of the earth, the instrument panel will be clearly visible under red or white light. If the astronaut is sufficiently dark adapted, the horizon will probably be visible and bright objects might be seen in the sky and possibly on earth. Navigation using check points on earth will probably not be possible, but celestial fixes might be used. Attitude control in pitch and roll might be feasible using the horizon, but marginal in yaw using star patterns.

RETROGRADE AND RE-ENTRY – The visual situation for a daylight re-entry is much as that for orbit except the chute might be visible through the window or the extended periscope. For a night re-entry, a sufficiently dark adapted astronaut will probably be able to distinguish the horizon through the window or periscope for backup attitude control during retrograde firing, especially with the periscope if the aurora begins to demarcate the eastern horizon. This represents a difficult visual task because of the lack of a clear earth-sky discontinuity. Star patterns might be used for yaw control.

CONCLUSIONS

The design of the Mercury vehicle has attempted to make inside and outside vision compatible under a variety of environmental and mission conditions. It is felt that an adequate compromise has been reached, considering the over-all systems requirement, and the wide range of conditions that will be encountered. Vision will be an extremely important and useful source of information for the astronaut.

Training can improve the astronaut's visual capability. Areas that might be emphasized are pattern recognition for the earth and sky, and instruction in the basic principles of vision and perception to assure that the best possible lighting combinations are used.

Further information concerning man's visual capability would be obtained best from orbital missions where adequate observation and recording are possible. Future research efforts might be directed profitably towards further enhancing man's vision in space.

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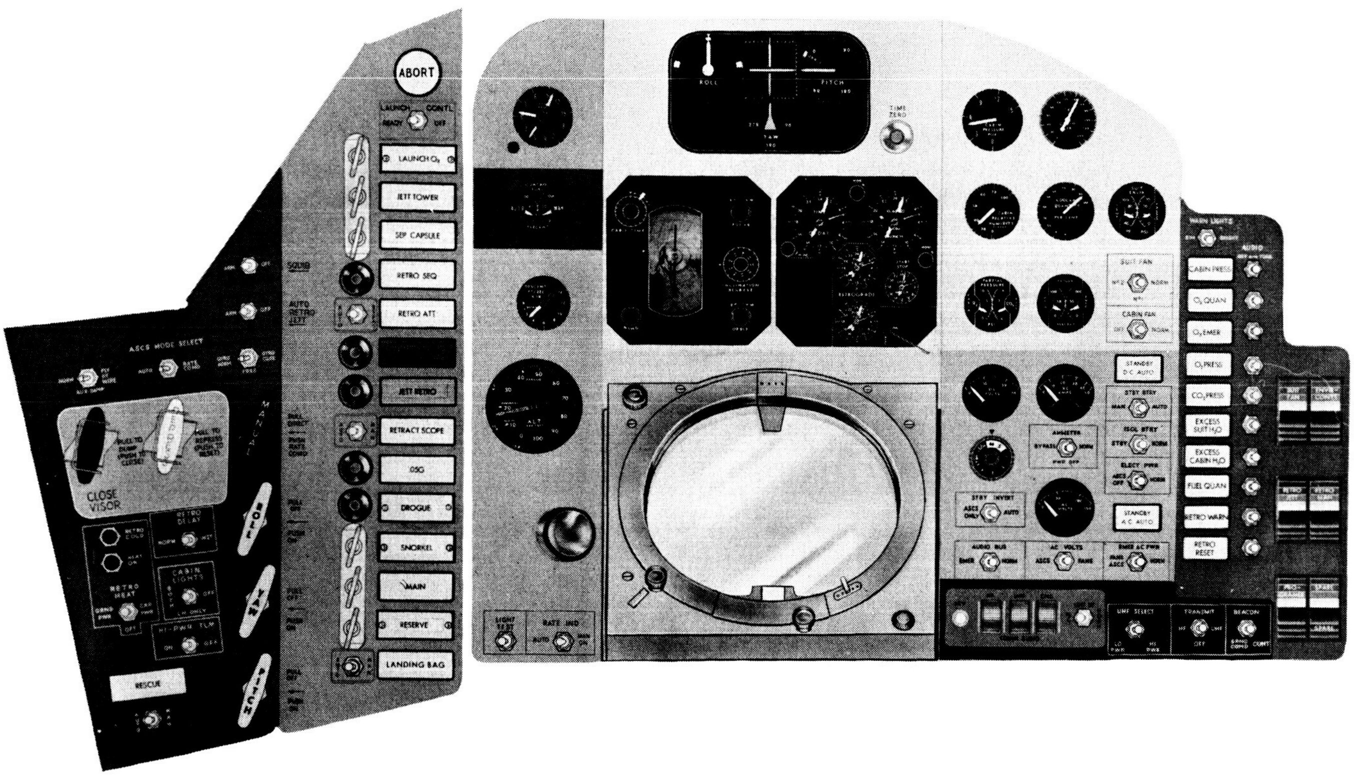

FIGURE 1 – MOCKUP OF MERCURY INSTRUMENT PANEL

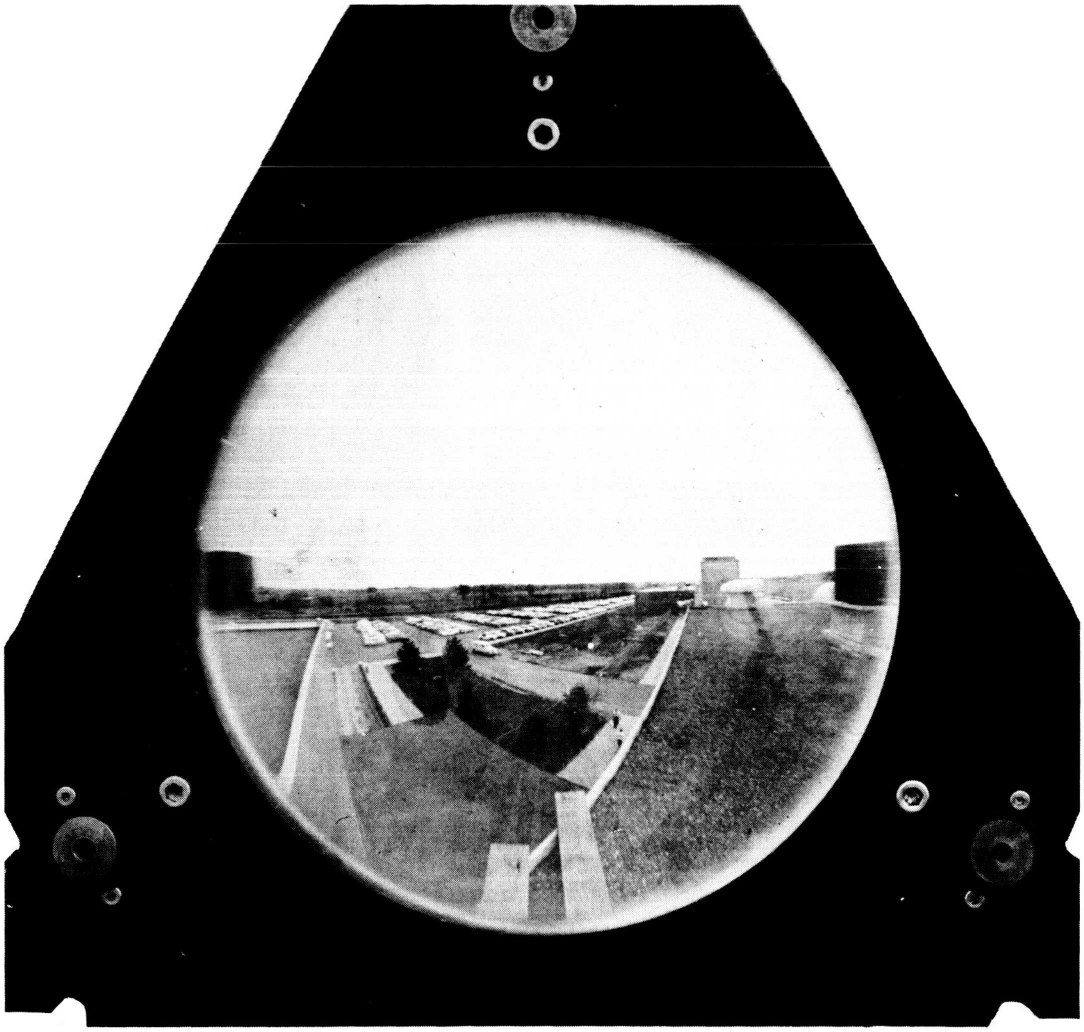

FIGURE 2 – VIEW THROUGH PROTOTYPE PERISCOPE SHOWING WIDE FIELD

FIGURE 3 – MOCKUP OF EARLY MERCURY CAPSULE INTERIOR SHOWING CENTERLINE WINDOW AND ITS FILTERS AND SHIELDS